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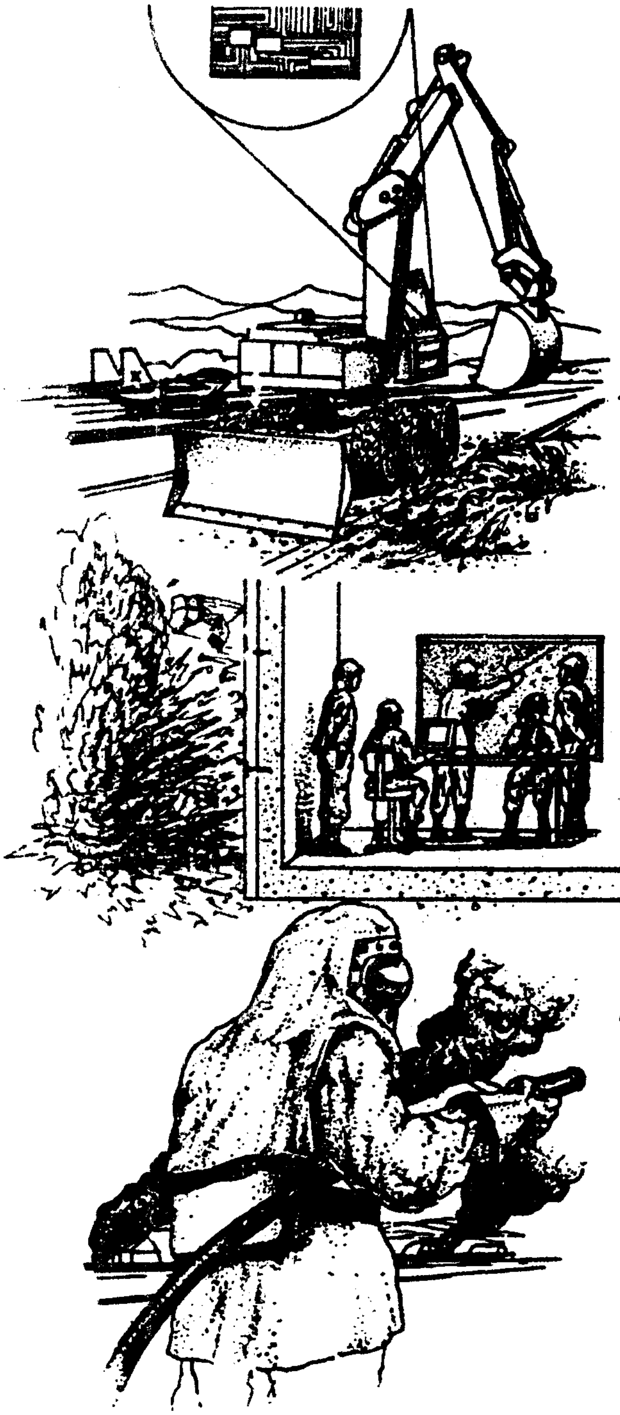

DURABILITY OF EXPEDIENT REPAIR MATERIALS

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MARCH 1993

FINAL REPORT

JUNE 1991 - SEPTEMBER 1991

APPROVED FOR PUBLIC RELEASE:
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ENGINEERING RESEARCH DIVISION
Air Force Civil Engineering Support Agency
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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
March 1993

3. REPORT TYPE AND DATES COVERED
Final 1 June 91 - 1 Sept 91

4. TITLE AND SUBTITLE
Durability of Expedient Repair Materials

5. FUNDING NUMBERS
C: F08635-88-C-0067

6. AUTHOR(S)
Muszynski, L.C.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Applied Research Associates, Inc.
P.O. Box 40128
Tyndall AFB, FL 32403

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Head Quarters Air Force Civil Engineering Support Agency
Civil Engineering Support Laboratory
Tyndall AFB, FL 32403-6001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
ESL-TR-92-20

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release
Distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The objective of this effort was to test and evaluate the durability of recently developed expedient repair materials and to compare their performance to standard commercial materials that have a proven track record of being durable. Testing included freeze-thaw, rapid chloride ion permeability, volume of permeable voids, and a time-to-corrosion test developed by the Flofida Department of Transportation.

14. SUBJECT TERMS
Expedient Repair Materials
Shotcrete
Air Force Base Civil Engineer (BCE)
Airbase Operability (ABO)

15. NUMBER OF PAGES
21

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
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EXECUTIVE SUMMARY

A. OBJECTIVE

The objective of this work was to test and evaluate the durability of recently developed expedient repair materials and compare their performance to standard commercial materials that have a proven track-record of being durable.

B. BACKGROUND

Durability of concrete is an important property because it is essential that concrete be able to withstand both external and internal conditions throughout its projected life. Durability can be defined as a materials' ability to last for a long time without significant deterioration.

Lack of durability is caused by external agents arising from the environment or internal agents within the concrete. Causes can be physical, mechanical or chemical. Physical causes can arise from the action of freezing and thawing or frost, whereby the capillary pores in the concrete matrix are filled with water which then freezes, resulting in a volume expansion. This in turn creates stresses in the concrete pore structure greater than the tensile strength of the concrete matrix.

C. EVALUATION METHODOLOGY

The expedient repair material used in the durability testing was based on Rapid-Set^{R}, a calcium sulfoaluminate cement produced by CTS Cement Company.

A dry process shotcrete standard, Microsil^{R}, and a State of Florida corrosion-resistant concrete system, referred to as Florida Class 4 concrete, were used as concrete durability standards.

The test methods employed in this evaluation program were ASTM C-666, Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing, Procedure A; ASTM-642, Standard Test Method for Specific Gravity, Absorption, and Voids in Hardened Concrete; AASHTO T-277, Standard Method of Test for Rapid

Determination of the Chloride Permeability of Concrete; and the Time-To-Corrosion Test developed by the Florida Department of Transportation.

D. RESULTS

This effort was curtailed due to the reorganization of the Air Force Engineering and Services Laboratory, RD, which eliminated the Materials group, under which this effort was being performed. The newly created Airbase Survivability Branch did not wish to continue the testing and evaluation effort in this area.

The abbreviated results illustrated the "short-term" durability of the rapid repair materials tested by conventional methods for determining durability.

E. CONCLUSIONS

The blended Rapid-Set^{R} shotcrete system appears to be as durable, according to the tests performed in this abbreviated study, as the commercially available Microsil^{R} shotcrete system.

F. RECOMMENDATIONS

This study should be reinitiated, and the long-term durability of these rapid-repair materials further evaluated.

PREFACE

This report was prepared by Applied Research Associates, Inc. (ARA), P.O. Box 40128, Tyndall Air Force Base, Florida 32403, under contract FO8635-88-C-0067, for the Air Force Civil Engineering Support Agency, Civil Engineering Laboratory, Engineering Research Division (AFCESA/RAC), Tyndall Air Force Base, Florida.

This report summarizes work done between 1 June 1991 and 1 September 1991. Mr. Paul Sheppard was the AFCESA/RACS Project Officer for the subtask under which this work was accomplished.

This report has been reviewed by the Public Affairs Office and is releasable to the National Technical Information Service (NTIS).

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCION

A. OBJECTIVE

The objective of this work was to train the support staff on the proper use of and procedures for performing durability testing according to American Society for Testing and Materials (ASTM) and American Association of State Highway and Transportation Officials (AASHTO) standards, and to test and evaluate the durability of recently developed expedient repair materials and compare their performance to standard commercial materials that are considered "durable."

B. BACKROUND

Durability of concrete is an important property because it is essential that concrete be able to withstand both external and internal conditions throughout its projected life. Durability can be defined as a materials' ability to last for a long time without significant deterioration.

Lack of durability is caused by external agents arising from the environment or internal agents within the concrete. Causes can be physical, mechanical or chemical. Physical causes can arise from the action of freezing and thawing or frost, whereby the capillary pores in the concrete matrix are filled with water which then freezes, resulting in a volume expansion. This in turn creates stresses in the concrete pore structure greater than the tensile strength of the concrete matrix.

Mechanical causes of loss of durability arise primarily from abrasion. Chemical causes include attack by chemical agents, including acids, sulfates, sea water, and chlorides, which induce electrochemical corrosion of steel reinforcement.

C. SCOPE/APPROACH

The expedient repair material used in the durability testing was based on Rapid-Set^{R}, a calcium sulfoaluminate cement produced by CTS Cement Company. Additionally, blended cement systems meeting the requirements of ASTM

C-595 (Reference 1), Standard Specifications for Blended Hydraulic Cements, were evaluated. A dry process shotcrete standard, Microsil[R], and a State of Florida corrosion resistant concrete system, referred to as Florida Class 4 concrete, were used as concrete durability standards.

The test methods employed in this evaluation program were ASTM C-666 (Reference 2), Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing, Procedure A; ASTM-642 (Reference 2), Standard Test Method for Specific Gravity, Absorption, and Voids in Hardened Concrete; AASHTO T-277 (Reference 3), Standard Method of Test for Rapid Determination of the Chloride Permeability of Concrete; and Florida Department of Transportation RR-206 (Reference 4), Time-To-Corrosion Test.

The materials tested and evaluated in this effort included Rapid-Set[R] cement shotcrete, Florida Class 4 concrete, Microsil[R] shotcrete, and Rapid-Set[R] cement blends. The Rapid-Set[R] cement was blended with class C fly ash, class F fly ash, and type 1 portland cement.

SECTION II

RESULTS

This effort was curtailed due to the reorganization of the Air Force Engineering and Services Laboratory, RD, which eliminated the Materials group, under which this effort was being performed. The newly created Airbase Survivability Branch did not wish to continue the testing and evaluation effort in this area.

A. FREEZE-THAW

The test results of ASTM C-666, Procedure A, Freezing in Water and Thawing in Water, are illustrated in Table 1 and Figure 1. The tests were conducted on two types of samples, the Rapid-Set^R cement shotcrete material (RS8) and a Rapid-Set^R-type 1 portland cement blend (RS4P7). RS8 represents specimens made from a mix design using eight sacks of Rapid-Set^R cement per cubic yard of concrete. RS4P7 represents specimens made from a mix design using 7 sacks of a 60:40 blend of Rapid-Set^R cement and type 1 portland cement repectively per cubic yard of concrete.

The test was curtailed due to the reorganization described previously. Normally this test is carried out to 300 freeze-thaw cycles. One freeze-thaw cycle includes approximately 4 hours for the temperature of the specimen immersed in water to drop from 40 F. to 0 F.(freezing), and 4 hours for the temperature of the specimen immersed in water to rise from 0 F. to 40 F.(thawing). The number of cycles at which the relative dynamic modulus of elasticity drops below 60 is considered failure. This occured at approximately 75 cycles for the Rapid-Set^R cement (RS) system. The Rapid-Set^R cement, blended with type 1 portland cement concrete system, demonstrated excellent resistance to freeze-thaw damage up to 115 cycles, when the test was stopped.

Table1. FREEZE-THAW RESULTS.

Sample	No. of Cycles	Weight Lb.	Length Inch	Width Inch	Depth Inch	Mass Density Lb-sec^2/in^4	Frequency Hz	Dynamic MOE Psi	Relative Dynamic MOE
RS8-1	0	15.44	16	4	3	0.000208	4895	5106602	100
RS8-2	0	15.51	16	4	3	0.000209	4892	5123206	100
RS8-3	0	15.42	16	4	3	0.000208	4831	4965066	100
RS4P7-1	0	15.68	16	4	3	0.000211	4972	5349672	100
RS4P7-2	0	15.66	16	4	3	0.000211	4963	5322230	100
RS4P7-3	0	15.63	16	4	3	0.000211	4931	5244350	100
RS8-1	30	15.46	16	4	3	0.000208	4884	5088684	99.5511
RS8-2	30	15.5	16	4	3	0.000209	4782	4891503	95.5534
RS8-3	30	15.45	16	4	3	0.000208	4828	4969184	99.8758
RS4P7-1	30	15.63	16	4	3	0.000211	5017	5429028	101.818
RS4P7-2	30	15.62	16	4	3	0.000211	4986	5360026	100.929
RS4P7-3	30	15.58	16	4	3	0.000210	4960	5289601	101.18
RS8-1	58	15.41	16	4	3	0.000208	4610	4520608	89.0944
RS8-2	58	15.45	16	4	3	0.000208	3925	3285327	67.369
RS8-3	58	15.38	16	4	3	0.000207	3700	2905884	58.7312
RS4P7-1	58	15.59	16	4	3	0.000210	5026	5433000	100.359
RS4P7-2	58	15.56	16	4	3	0.000210	4979	5321908	99.7194
RS4P7-3	58	15.53	16	4	3	0.000209	4937	5223084	99.0747
RS8-1	115	15.12	16	4	3	0.000204	1705	606557	13.6788
RS8-2	115	15.07	16	4	3	0.000203	2680	1493553	46.6219
RS8-3	115	14.34	16	4	3	0.000193	1820	655636	24.1958
RS4P7-1	115	15.47	16	4	3	0.000209	5020	5380245	99.7614
RS4P7-2	115	15.39	16	4	3	0.000207	4960	5224560	99.2383
RS4P7-3	115	15.32	16	4	3	0.000207	4945	5170764	100.324

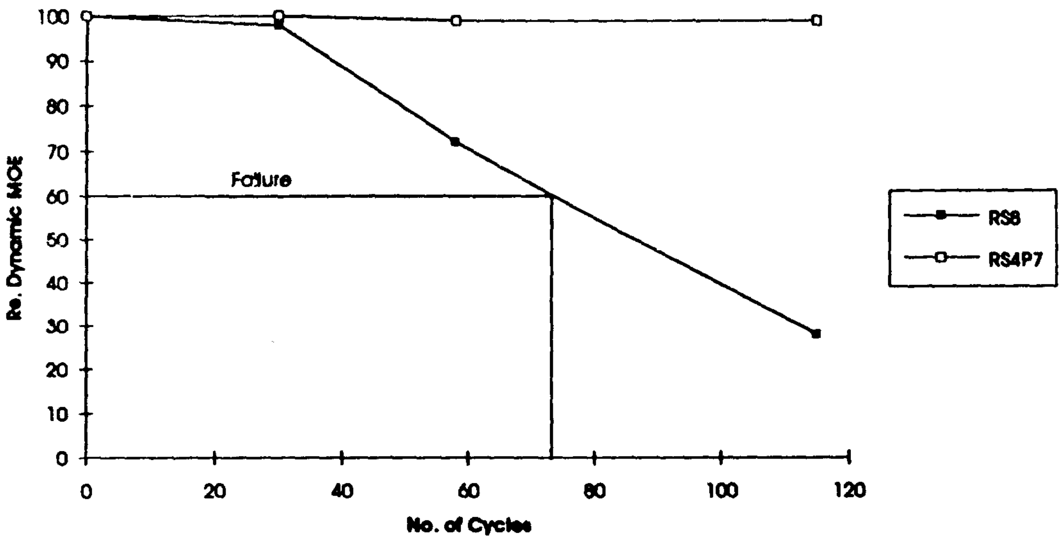

Figure 1. ASTM C-666 Freeze-Thaw Test Results.

B. VOLUME OF PERMEABLE VOIDS

This test is currently used as an indicator of dry-mix shotcrete quality or durability. Tests were performed on the Rapid-Set[R] cement shotcrete formulation(RS), Florida Class 4 concrete(FL4), Microsil[R] shotcrete(MSIL), Rapid-Set[R] cement blended with type 1 portland cement(RSP), class C fly ash(RSC), and class F fly ash(RSF). The materials were cured at three different curing conditions as shown in Table 2:

1 - 24 hour accelerated cure using hot water at 140°F.,

2 - 7 day moist cure at ambient temperature, and

3 - 28 day moist cure at ambient temperature.

Rapid repair material samples were prepared in the usual manner and cured according to the schedules described above. Specimens used to evaluate the volume of permeable voids, according to ASTM C-642, were cured without further conditioning. Companion specimens were used to determine their relative resistance to corrosion, according to the Florida DOT's Time-To-Corrosion test, and were conditioned after curing according to Table 2.

TABLE 2. SAMPLE CURE AND CONDITIONING SCHEDULE

SAMPLE	CURE CONDITION	CONDITIONING	SAMPLE	CURE CONDITION	CONDITIONING
FL4-1	1	24 HRS 5% NACL	RSC-1	1	24 HRS 5% NACL
FL4-2	1	28 DAYS 5% NACL	RSC-2	1	28 DAYS 5% NACL
FL4-3	2	7 DAYS 5% NACL	RSC-3	2	7 DAYS 5% NACL
FL4-4	3	28 DAYS 5% NACL	RSC-4	3	28 DAYS 5% NACL
FL4-1A/B	1	None	RSC1A/B	1	None
FL4-2A/B	2		RSC-2A/B	2	
FL4-3A/B	3		RSC-3A/B	3	
MSIL-1	1	24 HRS 5% NACL	RSF-1	1	24 HRS 5% NACL
MSIL-2	1	28 DAYS 5% NACL	RSF-2	1	28 DAYS 5% NACL
MSIL-3	2	7 DAYS 5% NACL	RSF-3	2.	7 DAYS 5% NACL
MSIL-4	3	28 DAYS 5% NACL	RSF-4	3	28 DAYS 5% NACL
MSIL-1A/B	1	None	RSF-1A/B	1	None
MSIL-2A/B	2		RSF-2A/B	2	
MSIL-3A/B	3		RSF-3A/B	3	
RS-1	1	24 HRS 5% NACL	RSP-1	1	24 HRS 5% NACL
RS-2	1	28 DAYS 5% NACL	RSP-2	1	28 DAYS 5% NACL
RS-3	2	7 DAYS 5% NACL	RSP-3	2	7 DAYS 5% NACL
RS-4	3	28 DAYS 5% NACL	RSP-4	3	28 DAYS 5% NACL
RS-1A/B	1	None	RSP-1A/B	1	None
RS-2A/B	2		RSP-2A/B	2	
RS-3A/B	3		RSP-3A/B	3	

The volume of permeable voids testing was performed according to ASTM C-642, and the results are shown in Table 3 and Figure 2. The results shown in Table 3 indicate the volume percent of voids that are accessable to water intrusion. The durability of concrete is inversely proportional to the percentage of permeable void volume. According to Table 3, the expected durability, in decreasing order, is FL4 and MSIL> RSP and RS>RSF and RSC .

TABLE 3. VOLUME OF PERMEABLE VOIDS TEST RESULTS.

Sample No.	Cure time Days	Bulk Specific Gravity (Dry)	Unit Wt. Pcf	Water Absorption Percent	Perm. Void Volume Percent
RSC-1	1	2.16	134.80	6.57	14.20
RSC-2	7	2.14	133.62	6.62	14.18
RSC-3	28	2.17	135.50	6.39	13.88
FL4-1	1	2.35	146.95	3.12	7.35
FL4-2	7	2.34	146.50	3.00	7.06
FL4-3	28	2.33	145.54	3.09	7.22
RSP-1B	1	2.15	134.25	5.50	11.84
RSP-2B	7	2.15	134.75	5.62	12.14
RSP-3B	28	2.14	133.94	5.53	11.88
RS-1B	1	2.14	134.07	5.31	11.42
RS-2B	7	2.16	134.80	5.16	11.16
RS-3B	28	2.15	134.17	5.62	12.10
RSF-1B	1	2.11	131.84	6.56	13.87
RSF-2B	7	2.10	131.29	6.30	13.26
RSF-3B	28	2.11	131.71	6.51	13.75
MSIL-1B	1	2.17	135.84	3.58	7.79
MSIL-2B	7	2.18	136.52	3.27	7.17
MSIL-3B	28	2.18	136.05	3.21	7.01

Figure 2 illustrates the results obtained in this study, as well as data points obtained from dry-process shotcrete materials used on actual jobs, as indicated by Study A and Study B (Reference 5). The volume of permeable voids relative to absorption after immersion and boiling has been correlated to shotcrete durablity by Morgan (Reference 5). The results indicate expected durability to be excellent for all material systems except the Rapid-Set^{R} cement shotcrete systems blended with class C and class F fly ash (RSC and RSF).

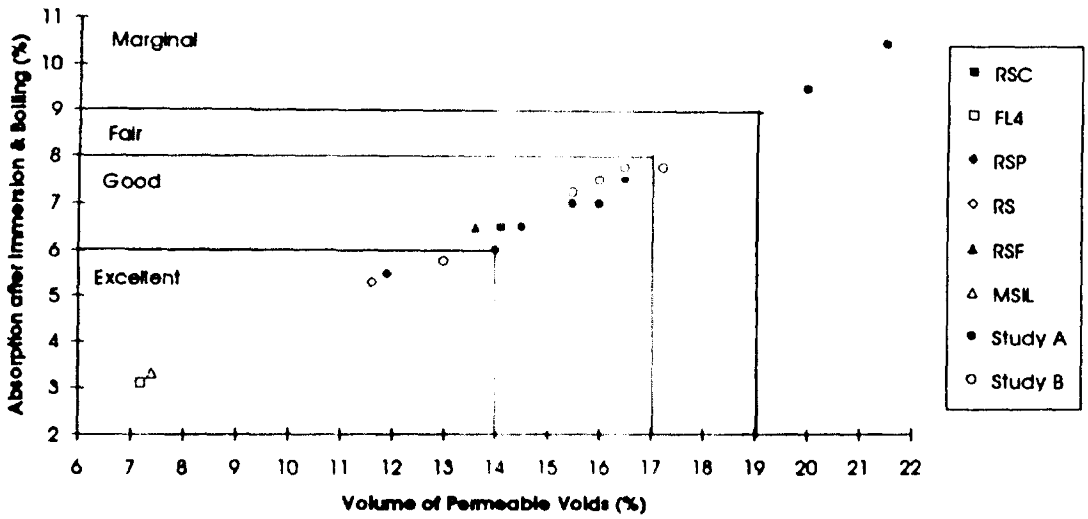

Figure 2. Durability of Shotcrete Materials

C. RAPID CHLORIDE ION PERMEABILITY

This test is currently used by most state DOTs to determine whether a shotcrete or concrete material will resist penetration by chloride ions, which are responsible for corroding steel reinforcement. According to AASHTO T-277, chloride ions are forced to travel through a concrete test specimen toward the positive electrode (cathode), and the resistance of the material to this penetration is referred to as the Coulomb number. The number of Coulombs is measured as the area under an amperage versus time curve up to 360 minutes. The data shown in Tables 4 and 5, and Figures 3, 4, 5, and 6, corresponds to the cure and conditioning schedule of samples shown in Table 2.

The results from Figure 6 indicate the shotcrete material systems most resistant to chloride ion penetration after 28 day curing and 28 day conditioning are, in descending order: MSIL, RSP, RSC, FL4, RS, and RSF

TABLE 4. CURRENT VERSUS TIME FOR SAMPLES CURED AND CONDITIONED BY SCHEDULES 1 AND 2.

Time, min	Current mA RS1	Current mA RSC1	Current mA RSP1	Current mA RSF1	Current mA MSIL1	Current mA FL41
0	0.225	0.102	0.023	0.267	0.021	0.107
30	0.245	0.101	0.026	0.326	0.022	0.113
60	0.264	0.11	0.025	0.345	0.023	0.119
90	0.269	0.112	0.025	0.379	0.023	0.124
120	0.275	0.115	0.025	0.445	0.024	0.128
150	0.291	0.116	0.025	0.531	0.024	0.13
180	0.316	0.116	0.026	0.655	0.025	0.131
210	0.346	0.116	0.026	0.795	0.025	0.131
240	0.383	0.114	0.027	0.796	0.025	0.132
270	0.432	0.112	0.027	0.66	0.026	0.132
300	0.452	0.11	0.028	0.328	0.026	0.131
330	0.334	0.108	0.027	0.203	0.026	0.13
360	0.266	0.106	0.028	0.131	0.026	0.13
Coulombs	6920	2400	560	10270	530	2735

Time, min	Current mA RS2	Current mA RSC2	Current mA RSP2	Current mA RSF2	Current mA MSIL2	Current mA FL42
0	0.252	0.081	0.014	0.325	0.022	0.094
30	0.287	0.083	0.014	0.359	0.022	0.101
60	0.303	0.082	0.014	0.395	0.023	0.111
90	0.306	0.082	0.014	0.424	0.023	0.117
120	0.313	0.082	0.015	0.486	0.024	0.121
150	0.342	0.082	0.015	0.58	0.024	0.126
180	0.374	0.082	0.015	0.69	0.024	0.129
210	0.415	0.082	0.015	0.752	0.024	0.132
240	0.466	0.082	0.015	0.604	0.024	0.132
270	0.515	0.082	0.015	0.315	0.024	0.132
300	0.508	0.08	0.015	0.228	0.025	0.131
330	0.487	0.078	0.015	0.14	0.026	0.13
360	0.461	0.077	0.016	0.156	0.026	0.129
Coulombs	8429	1758	318	9340	516	2654

TABLE 5. CURRENT VERSUS TIME FOR SAMPLES CURED AND CONDITIONED BY SCHEDULES 3 AND 4.

Time, min	Current mA RS3	Current mA RSC3	Current mA RSP3	Current mA RSF3	Current mA MSIL3	Current mA FL43
0	0.233	0.098	0.037	0.255	0.025	0.082
30	0.25	0.098	0.039	0.287	0.025	0.091
60	0.26	0.098	0.039	0.305	0.025	0.096
90	0.265	0.099	0.04	0.318	0.025	0.101
120	0.266	0.099	0.041	0.358	0.026	0.107
150	0.28	0.1	0.042	0.399	0.026	0.11
180	0.298	0.099	0.043	0.452	0.027	0.113
210	0.315	0.099	0.044	0.504	0.027	0.114
240	0.339	0.099	0.044	0.49	0.027	0.115
270	0.365	0.099	0.044	0.503	0.027	0.117
300	0.394	0.097	0.044	0.45	0.028	0.118
330	0.42	0.096	0.044	0.4	0.028	0.12
360	0.414	0.094	0.045	0.35	0.028	0.12
Coulombs	6805	2124	910	8615	571	2347

Time, min	Current mA RS4	Current mA RSC4	Current mA RSP4	Current mA RSF4	Current mA MSIL4	Current mA FL44
0	0.138	0.078	0.031	0.14	0.027	0.09
30	0.146	0.077	0.033	0.164	0.027	0.099
60	0.149	0.079	0.033	0.178	0.028	0.106
90	0.149	0.081	0.036	0.191	0.029	0.11
120	0.145	0.081	0.036	0.212	0.029	0.116
150	0.142	0.081	0.038	0.237	0.029	0.12
180	0.142	0.081	0.039	0.26	0.03	0.123
210	0.144	0.08	0.04	0.283	0.029	0.125
240	0.145	0.078	0.04	0.3	0.03	0.125
270	0.147	0.078	0.04	0.328	0.03	0.125
300	0.15	0.077	0.041	0.359	0.03	0.124
330	0.154	0.077	0.042	0.384	0.03	0.123
360	0.159	0.076	0.042	0.404	0.03	0.123
Coulombs	3172	1705	820	5706	628	2525

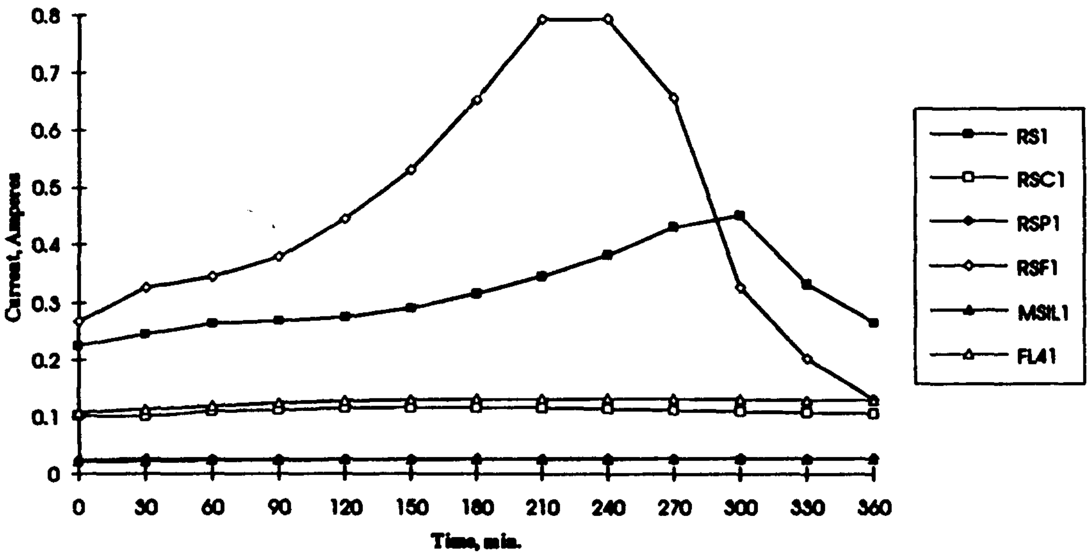

Figure 3. Current versus Time for Binders at Cure/Conditioning Schedule No. 1.

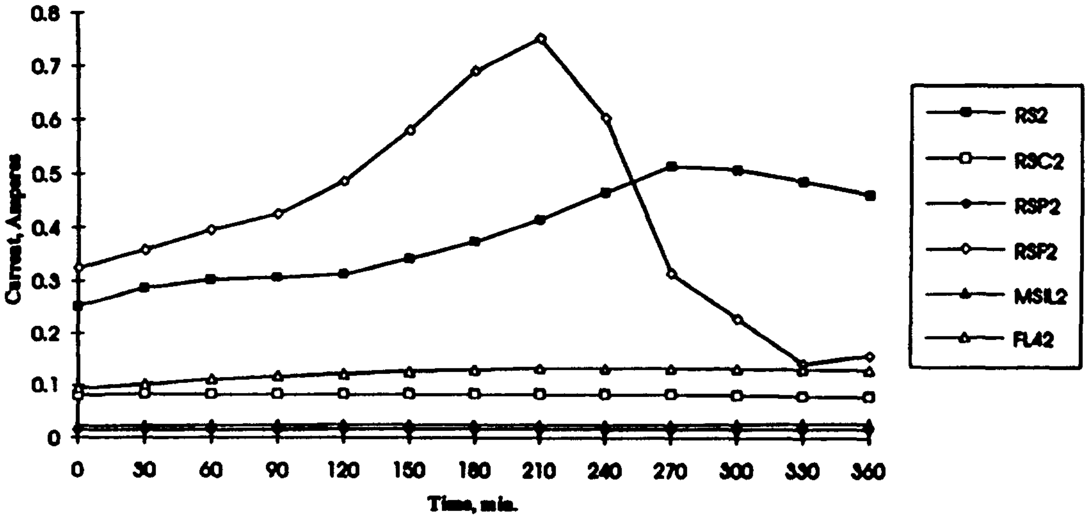

Figure 4. Current versus Time for Binders at Cure/Conditioning Schedule No. 2.

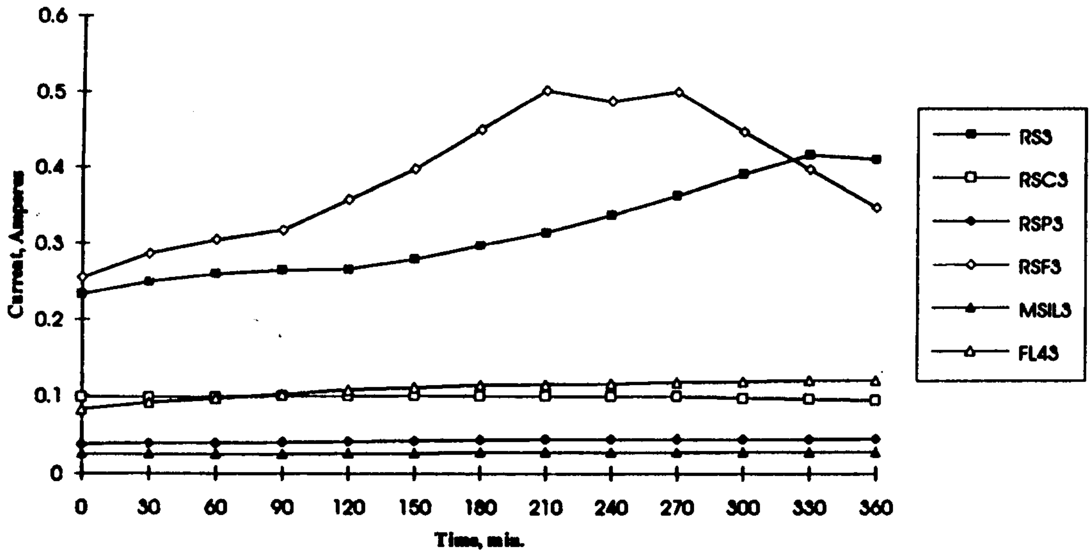

Figure 5. Current versus Time for Binders at Cure/Conditioning Schedule No. 3.

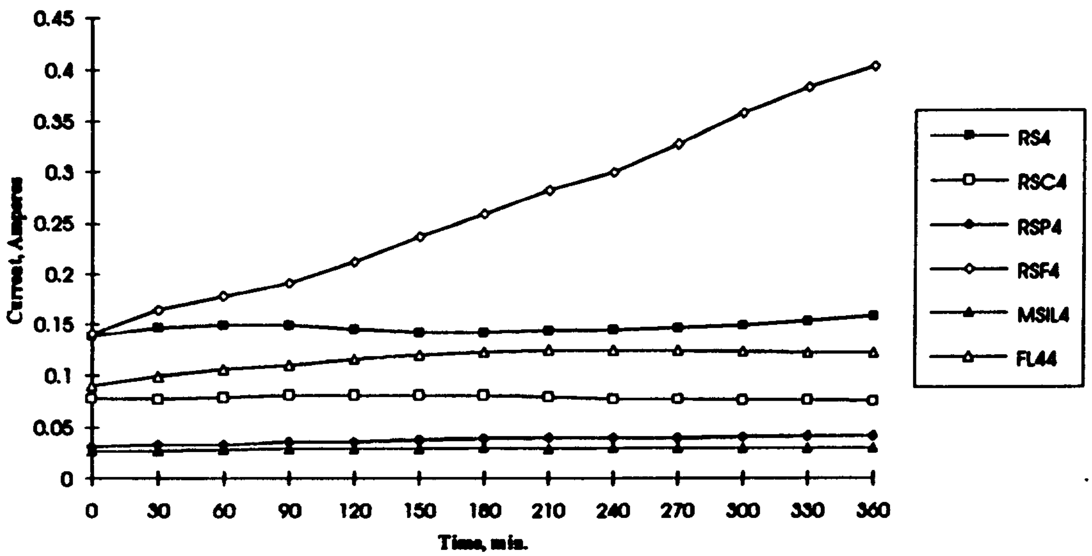

Figure 6. Current versus Time for Binders at Cure/Conditioning Schedule No. 4.

D. TIME-TO-CORROSION

This test was developed by the State of Florida Department of Transportation(DOT) to evaluate concrete/shotcrete resistance to chloride ion attack. This test requires a significant amount of time to complete, 30 to 360 days, relative to the Rapid Choride Permeability Test. It was developed to be an accelerated test relative to the previous "ponding" tests used by the Federal Highway Administration (FHWA). The tests were performed according to FDOT Research Report 206. The data is shown in Table 6, and in Figures 8,9,10,11,12 and 13. Unfortunately, experimental problems were encountered in obtaining the data. The problems were primarily aassociated with the electrical elements of the tests, i.e. power supply, shunts, etc. The testing was stopped prior to eliminating these "bugs," due to the reorganization.

TABLE 6. TIME-TO-CORROSION DATA.

Day Sample	6 Voltage mV	7 Voltage mV	8 Voltage mV	9 Voltage mV	10 Voltage mV	11 Voltage mV	12 Voltage mV	13 Voltage mV
RS2	0.004	0.0012	0.0012	0.0012	0.0009	0.0008	0.0005	0.0006
RS1	0.004	0.0009	0.0009	0.0009	0.0003	0.0003	0.0003	0.0002
MSIL2	0.002	0.0018	0.0018	0.0018	0.0013	0.0012	0.0008	0.0008
MSIL1	0.002	0.002	0.002	0.002	0.0012	0.0011	0.0008	0.0007
RSF1	0	0.0036	0.0018	0.0018	0.0018	0.0018	0.0021	0.0023
FL41	0	0	0.0002	0.0002	0.0005	0.0004	0.0003	0.0003
RSC2	0	0.0015	0.0003	0.0003	0.0003	0.0002	0.0002	0.0003
FL42	0	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0004
RSP1	0	0.0018	0.0003	0.0003	0.0003	0.0002	0.0001	0.0001
RSP2	0	0.0017	0.0003	0.0003	0.0003	0.0003	0.0002	0.0002
RSF2	0	0.0056	0.002	0.002	0.002	0.0022	0.002	0.0023
RSC1	0	0.0035	0.0004	0.0004	0.0004	0.0003	0.0003	0.0006
RSF2A	0	0	0	0	0	0	0	0
RSF3	0	0	0	0	0	0	0	0
RSP3	0	0	0	0	0	0	0	0
MISL3	0	0	0	0	0	0	0	0
RSC3	0	0	0	0	0	0	0	0

TABLE 6. TIME-TO-CORROSION DATA (CONTINUED)

Day Sample	14 Voltage mV	15 Voltage mV	16 Voltage mV	17 Voltage mV	18 Voltage mV	19 Voltage mV	20 Voltage mV	21 Voltage mV
RS2	0.0008	0.0008	0.0008	0.0006	0.0005	0.0002	0.0003	0.0003
RS1	0.0003	0.0003	0.0003	0.0003	0.0003	0.0002	0.0004	0.0004
MSIL2	0.0007	0.0007	0.0007	0.0005	0.0002		0.0001	0.0002
MSIL1	0.0006	0.0006	0.0006	0.0004	0.0001		0.0002	0.0002
RSF1	0.0027	0.0027	0.0027	0.0027	0.0027	0.0017	0.0017	0.0019
FL41	0.0002	0.0002	0.0002	0.0003	0.0003	0.0001	0.0002	0.0003
RSC2	0.0005	0.0005	0.0005	0.0006	0.0008	0.0005	0.0007	0.0007
FL42	0.0002	0.0002	0.0002	0.0004	0.0006	0.0002	0.0004	0.0004
RSP1	0.0001	0.0001	0.0001	0.0004	0.0006	0.0001	0.0002	0.0002
RSP2	0.0001	0.0001	0.0001	0.0004	0.0006	0.0001	0.0002	0.0001
RSF2	0.0025	0.0025	0.0025	0.0029	0.0034	0.0019	0.0019	0.0027
RSC1	0.0007	0.0007	0.0007	0.0011	0.0016	0.0013	0.0014	0.0013
RSF2A	0	0	0	0	0	0	0	0.0027
RSF3	0	0	0	0	0	0	0	0
RSP3	0	0	0	0	0	0	0	0
MISL3	0	0	0	0	0	0	0	0
RSC3	0	0	0	0	0	0	0	0

Day Sample	22 Voltage mV	23 Voltage mV	24 Voltage mV	25 Voltage mV	26 Voltage mV	27 Voltage mV	28 Voltage mV	29 Voltage mV
RS2	0.0003	0.0003	0.0005	0.0006	0.0006	0.0007	0.0007	0.0007
RS1	0.0004	0.0004	0.0006	0.0007	0.0008	0.0008	0.0009	0.0009
MSIL2	0.0002	0.0002	0.0001	0.0002	0.0001	0.0001	0.0002	0.0002
MSIL1	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002
RSF1	0.003							
FL41	0.0003	0.0003	0.0002	0.0003	0.0002	0.0002	0.0002	0.0002
RSC2	0.0007	0.0007	0.0007	0.0008	0.0008	0.0007	0.0007	0.0007
FL42	0.0004	0.0004	0.0004	0.0004	0.0003	0.0002	0.0002	0.0002
RSP1	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
RSP2	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
RSF2	0.0027	0.0027						
RSC1	0.0013	0.0013	0.0013	0.0014	0.0014	0.0015		
RSF2A	0.0003	0.0003	0.0003	0.0005	0.0004	0.0005	0.0005	0.0005
RSF3	0	0	0.0031	0.003	0.0028	0.0028	0.0023	0.0023
RSP3	0	0	0	0	0	0	0.0004	0.0004
MISL3	0	0	0	0	0	0	0	0
RSC3	0	0	0	0	0	0	0	0

TABLE 6. TIME-TO-CORROSION DATA (CONTINUED)

Day / Sample	30 Voltage mV	1 Voltage mV	2 Voltage mV	3 Voltage mV	4 Voltage mV	5 Voltage mV	6 Voltage mV	7 Voltage mV
RS2	0.0007	0.0011	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012
RS1	0.0009	0.0012	0.0013	0.0015	0.0015	0.0016	0.0016	0.0016
MSIL2	0.0002	0.0003	0.0003	0.0004	0.0004	0.0005	0.0005	0.0005
MSIL1	0.0002	0.0003	0.0003	0.0003	0.0003	0.0005	0.0005	0.0005
RSF1								
FL41	0.0002	0.0002	0.0002	0.0003	0.0003	0.0003	0.0003	0.0003
RSC2	0.0007	0.0006	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
FL42	0.0002	0.0003	0.0003	0.0004	0.0004	0.0003	0.0003	0.0003
RSP1	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
RSP2	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
RSF2								
RSC1								
RSF2A	0.0005	0.0006	0.0006	0.0006	0.0006	0.0007	0.0007	0.0007
RSF3	0.0023	0.0016	0.0017	0.0019	0.0019	0.0017	0.0017	0.0017
RSP3	0.0004	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
MISL3	0	0	0	0	0	0	0	0
RSC3	0	0	0	0	0	0	0	0

Day / Sample	8 Voltage mV	9 Voltage mV	10 Voltage mV	11 Voltage mV	12 Voltage mV	13 Voltage mV	14 Voltage mV	15 Voltage mV
RS2	0.0015							
RS1	0.0019							
MSIL2	0.0005	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
MSIL1	0.0005	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001
RSF1								
FL41	0.0002	0.0002	0.0002	0.0002	0.0003	0.0003	0.0003	0.0004
RSC2	0.0009	0.0008	0.0008					
FL42	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
RSP1	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
RSP2	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
RSF2								
RSC1								
RSF2A	0.0008	0.0007	0.0008	0.0008	0.0008	0.0008	0.0008	0.0009
RSF3	0.0018	0.0014	0.0015					
RSP3	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
MISL3	0.0006	0.0002	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001
RSC3	0.0029	0.0005	0.0006	0.0005	0.0005	0.0005	0.0005	0.0005

TABLE 6. TIME-TO-CORROSION DATA (CONTINUED)

Day Sample	16 Voltage mV	17 Voltage mV	18 Voltage mV	19 Voltage mV	20 Voltage mV	21 Voltage mV	22 Voltage mV	Voltage mV
RS2								
RS1								
MSIL2	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	
MSIL1	0.0001	0.0001	0.0003	0.0004	0.0004	0.0004	0.0004	
RSF1								
FL41	0.0004	0.0005	0.0007	0.0008	0.0008	0.0008	0.0012	
RSC2								
FL42	0.0003	0.0002	0.0003	0.0003	0.0003	0.0003	0.0002	
RSP1	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	
RSP2	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	
RSF2								
RSC1								
RSF2A	0.0009	0.0008	0.0009	0.0009	0.0009	0.0009	0.0009	
RSF3								
RSP3	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	
MISL3	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	
RSC3	0.0005	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	

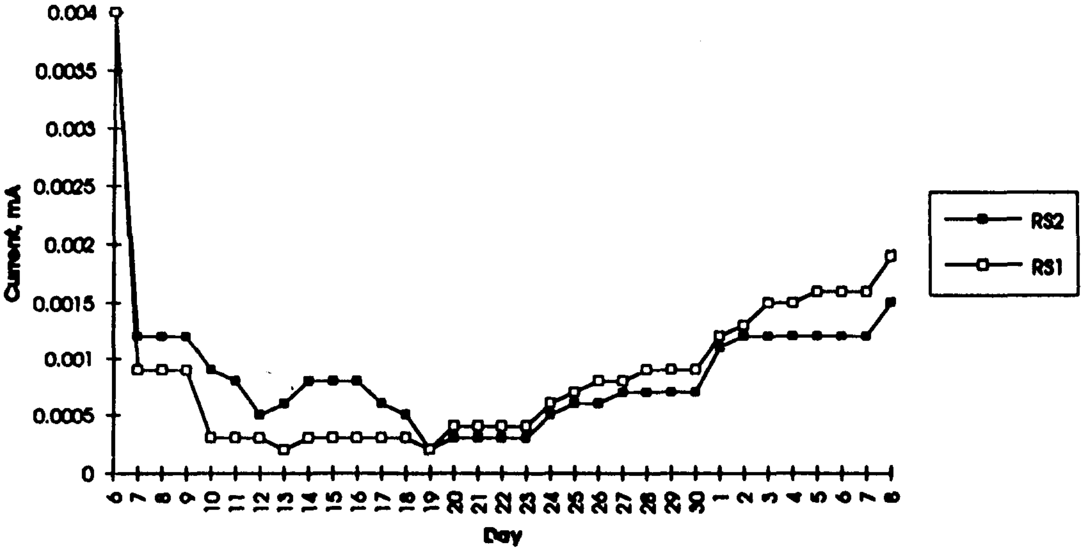

Figure 7. Time-toCorrosion (Rapid-Set^{R} (RS))

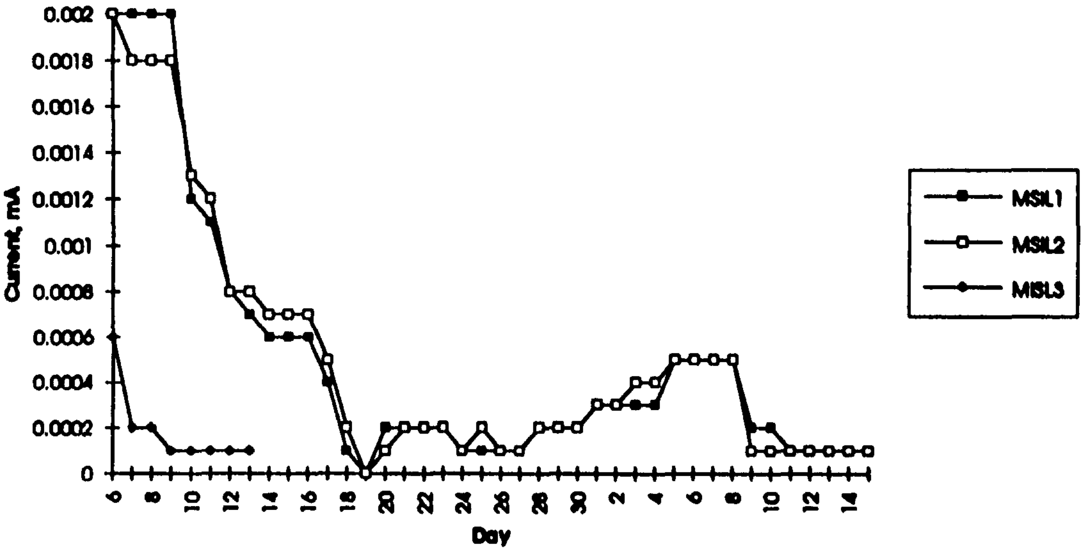

Figure 8. Time-to-Corrosion (Microsil^{R})

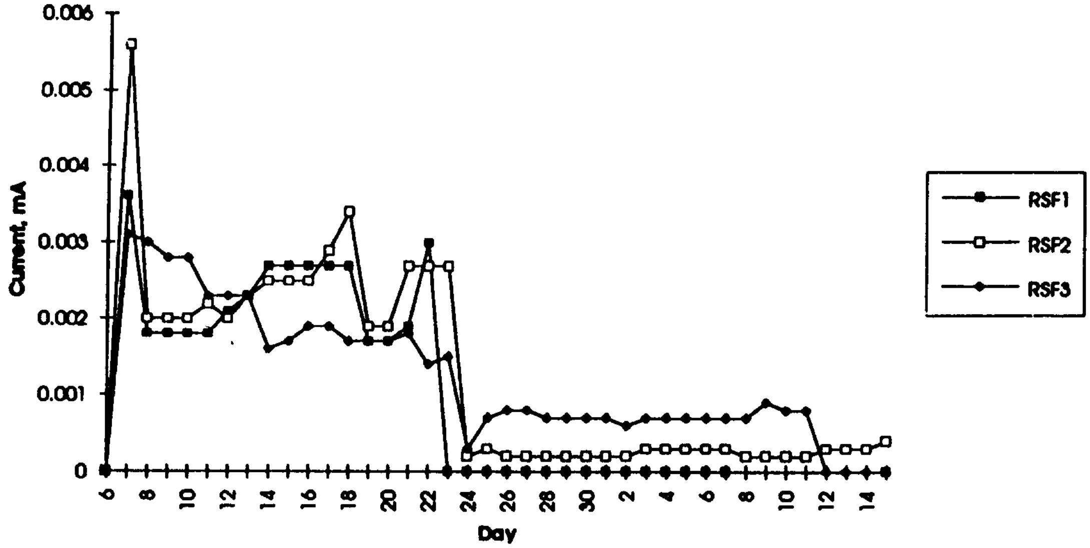

Figure 9. Time-to-Corrosion (RS w. F Ash)

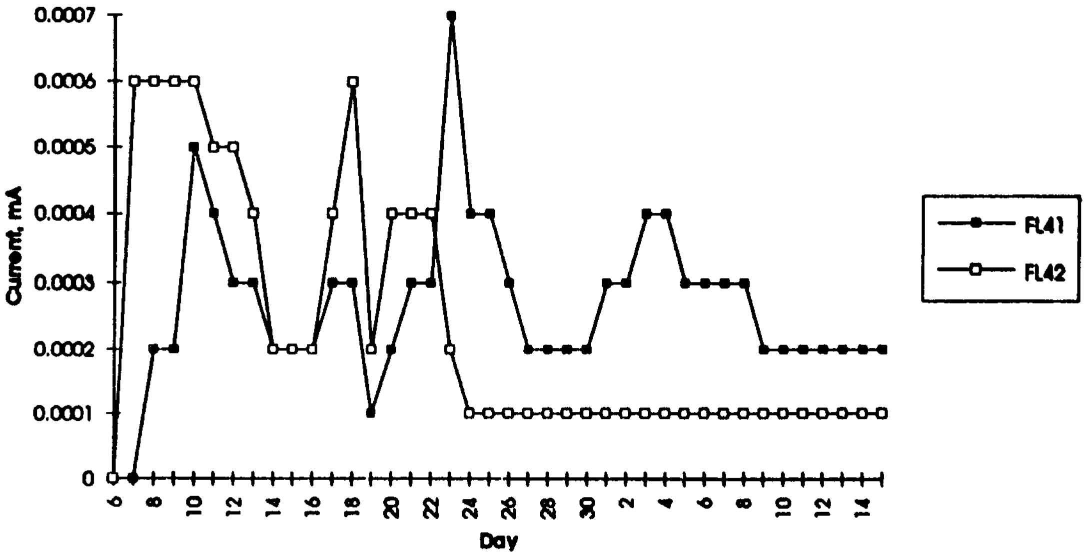

Figure 10. Time-to-Corrosion (Florida Class 4)

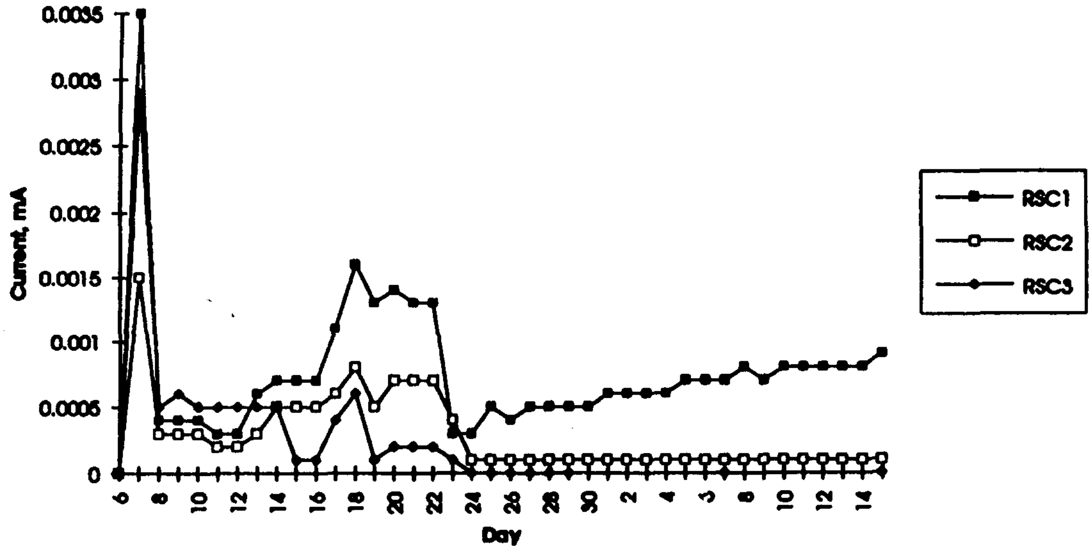

Figure 11. Time-to-Corrosion (RS w. C Ash)

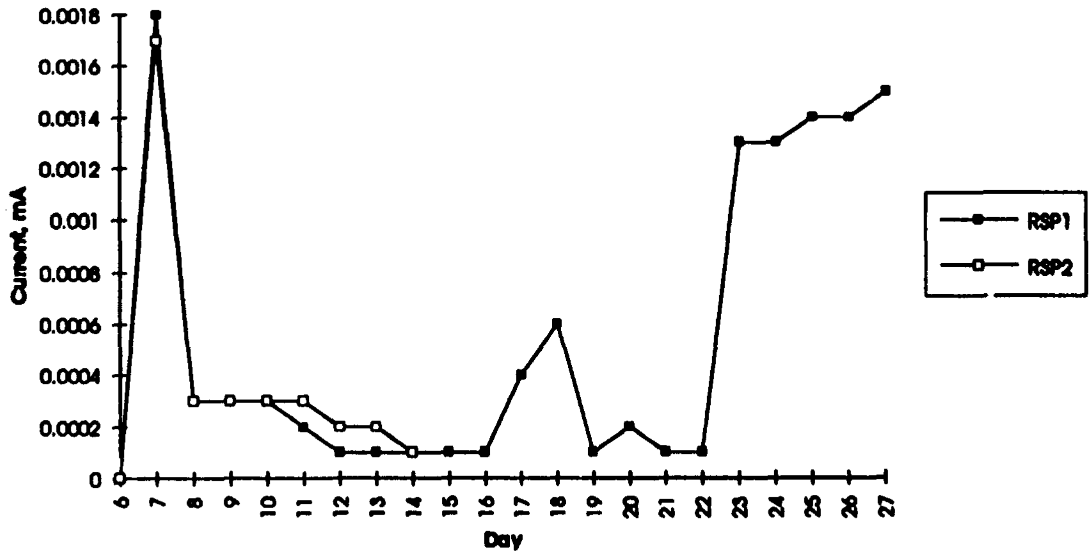

Figure 12. Time-to-Corrosion (RS w. Type 1 PC)

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS:

1. The Rapid-Set^{R} cement shotcrete system (RS) and the Rapid-Set^{R} system blended with type 1 portland cement (RSP) appear to offer excellent durability according to the data provided in Figure 2, but do not offer the same resistance to freeze-thaw damage or penetration of chloride ions as does the RSP system.

2. The blended Rapid-Set^{R} shotcrete system appears to be as durable (according to the tests performed in this abbreviated study) as the commercially available Microsil^{R} shotcrete system.

B. RECOMMENDATIONS

This study should be reinitiated, and the long-term durability of these rapid-repair materials further evaluated.

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5. Morgan, D.R., "High Early Strength Blended Cement Wet-Mix Shotcrete," Concrete International, Vol. 13, No. 5, May 1991, pp.35-39.